(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 878 776 A1

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
18.11.1998 Bulletin 1998/47

(51) Int. Cl.^{6}: **G06T 1/00**, G06T 5/20

(21) Application number: 97830217.2

(22) Date of filing: 12.05.1997

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IE IT LI LU MC NL PT SE

(71) Applicant:
STMicroelectronics S.r.l.
20041 Agrate Brianza MI (IT)

(72) Inventors:
- Mancuso, Massimo
  20052 Monza (IT)
- D'Alto, Viviana
  20134 Milano (IT)
- Sirtori, Daniele
  00050 Cerveteri (IT)
- Poluzzi, Rinaldo
  20125 Milano (IT)

(74) Representative:
Pellegri, Alberto et al
c/o Società Italiana Brevetti S.p.A.
Via Puccini, 7
21100 Varese (IT)

(54) **Adaptive intrafield reducing of gaussian noise by fuzzy logic processing**

(57) The level of Gaussian noise in a memory field being scanned by rows is reduced by reconstructing each pixel by fuzzy logic processors, the latter processing the the values of pixels neighbouring the pixel being processed and belonging to a processing window defined by the last scanned row and the row being scanned, thus minimizing the memory requisite of the filtering system to a single row. The system perform an adaptive filtering within the current field itself and does not produce "edge-smoothing" effects as in prior adaptive filtering systems operating on consecutive fields.

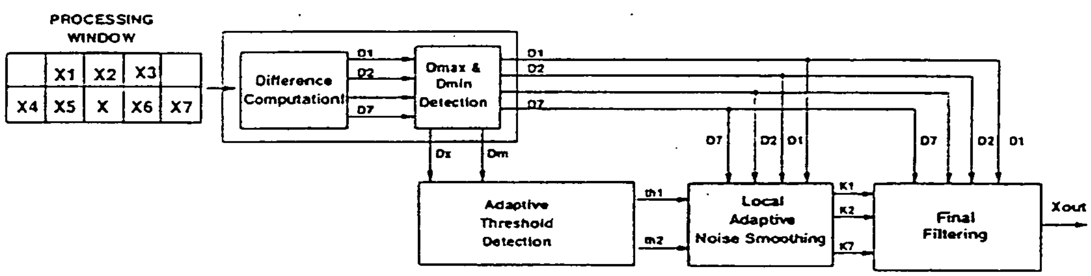

FIG. 4

EP 0 878 776 A1

Description

FIELD OF APPLICATION OF THE INVENTION

The present invention relates to an adaptive filtering system to reduce the level of Gaussian noise in a memory field being scanned by rows. More in particular the system of the invention is adapted to reduce the noise of an image to be displayed on screen by implementing an adaptivity in response to brightness changes, according to a predefined sensorial response system.

BACKGROUND OF THE INVENTION

Noise is inherent to any communication system and, in television broadcasting networks, originates in different ways.

At the source of image, noise may be either generated by photon or thermal noise in a videocamera or by granular noise in films of cameras. Signal processing circuits and recorder play back systems add noise because the signal circulates in an intrinsically noisy loop.

Finally, the signal may be carried to the transmitter via a distribution network that adds more noise, and broadcast via an intrinsically noisy transmission medium. The receiver circuits themselves add noise. Many techniques have been developed to reduce the problem of Gaussian noise and these are described in literature. The adaptivity of noise level to a certain image/video sequence is a key feature of the so-called "clever" filters.

Generally, this adaptivity is obtained using non linear techniques such as averaging filters or filters with variable behavior depending on the estimation of some parameters.

For instance, many known filters are obtained using scale and position estimates, or by estimating the temporal correlation (Recursive Averaging Filters) which is the most common techniques presently used in TV environments.

These known techniques have intrinsic disadvantages and/or limitations. In the case of a video sequence strongly affected by noise, the filter may confuse the noise with motion effects resulting in a poor noise reduction effect. To better this situation, the user could automatically select amongst a set of preordered response characteristics such as to dynamically accentuate or reduce the filtering effect. However, these systems of arbitrary selection influences the temporal frequency, introducing a sort of "comet effect" which may becomes more annoying than an excessive edge smoothing. On the other hand, motion detection requires at least one field memory in the recursive loop of the filter with the consequent increment of total memory requisite of the system.

SCOPE AND SUMMARY OF THE INVENTION

It is evident the need and/or utility for a Gaussian noise filtering system that minimizes the memory requisite for noise filtering and that introduces an adaptivity to the local picture characteristics based on the sensorial response to brightness changes of the so-called Human Visual System without penalizing edge definition by an undue smoothing. The filtering system of the invention provides for an effective response to these important requisites by processing data relative exclusively to a certain memory field, thus minimizing the memory requisite. The essential characteristic of the system of the invention is the utilization of a fuzzy logic process which allows for a current definition of the adaptivity parameters bearing in mind the characteristics of a certain scheme of sensorial response, such as for example the scheme of response to brightness changes known as the Human Visual System (HVS). The method of the invention permits to curt the noise affecting a certain area of a field scanned by rows, without employing information devided from a preceding field or picture which, by contrast, is the classic approach of the known systems wherein the noisy pixel is substituted with an averaged pixel value of the nearby ones belonging to a certain processing window.

This known approach has indeed the serious disadvantage of smoothing the edges and the contours of the objects depressing image definition.

By contrast, according to the present invention, each noisy pixel singled out within a certain processing window, is substituted with a weighted average of the surrounding pixels, according to a prestablished degree of similarity between the same pixel to be substituted and each of the nearby ones.

In this manner, if K_i provides a measure of the degree of similarity between the pixel X to be filtered and a generic pixel X_i belonging to the process window, the output filtered pixel value is given by:

$$X(i)_{out} = K_i * X + (1-K_i) * X_i \qquad (1)$$

If K_i is equal to 0, X and X_i are equal and thereby X may be substituted with X_i. Contrarily, if K_i is equal to 1, X and X_i are radically different from each other and in this situation their exchange would introduce a serious error. Therefore, according to the present invention, the filter output is obtained through a superimposition of the effects of several ele-

mentary filters whose function is described by equation (1), and such that the output pixel is expressed by the following relationship:

$$X_{out} = \Sigma\ X(i)_{out} = \frac{1}{N} + [\ \Sigma\ K_i * X + (1-K_i) * X_i] \qquad (2)$$

wherein:

X represents the value relative to the gray level of the pixel being processed;

X_i represents the value relative to the gray level of a pixel of neighbouring the pixel under processing

K_i provides the measure of similarity between the pixel X and the adjacent pixel X_i, in practice K_i represents the value produced by a fuzzy logic processing block according to a membership function corresponding to the sentence "*the difference between the pixels is low*".

N is the number of neighbouring pixels considered.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a processing window

Figure 2 is an example of the membership function used to weigh the computed differences between the pixel under processing and the neighbouring pixels within the processing window of Figure 1.

Figure 3 depicts a suitable membership function for generating the processing coefficients of a weighed average.

Figure 4 is a basic scheme of a Gaussian noise filtering system according to the present invention.

Figure 5 shows a block diagram of a circuit for defining a certain processing window.

Figure 6 is a diagram of the computation blocks of the absolute values of the differences and extraction of the minimum difference and of the maximum difference.

Figure 7 is a functional diagram of the fuzzy logic processing block of the pixel being processed and of the minimum and maximum differences to generate a pair of adaptive threshold values.

Figure 8 is a functional diagram of the plurality of fuzzy logic processing blocks of each computed difference to generate a set of weighed coefficients that affect an identical number of elementary filters and of the adder block regenerating the output pixel value.

DESCRIPTION OF THE METHOD OF THE INVENTION

Let us consider a processing window as the one shown in Figure 1, being X the pixel to be processed. The pixels X1, X2, X3 are the pixels of a scan line preceding the current scan line to which the pixel to be processed belongs neighbouring the pixel X, whereas X4, X5, X6 and X7 represent neighbouring pixels of the pixel X_i belonging to the current scan line.

According to a fundamental aspect of the invention the system must preliminarily carry out an estimation of the noise level.

For this purpose, the system computes the absolute values of the differences D_i between the pixel to be filtered. X and the neighbouring ones, X_i, and finds the maximum difference D_{max} and the minimum difference D_{min} among the absolute values of the computed differences D_i.

Using a fuzzy logic processing, different membership functions can be found that fulfill the sentence: "*the absolute difference value* $|D_i|$ *is small*", but if, by hypothesis, the produced value K_i varies according to the following law:

$$K_i = \frac{D_{max}}{D_{max}-D_{min}} - \frac{|D_i|}{D_{max}-D_{min}} \qquad (3)$$

several drawbacks would arise:

i) if the processing window does not contain edges, or boundaries of objects or features, D_{max} and D_{min} will be exclusively correlated to the noise, which therefore would not be significantly reduced;
ii) on the contrary, if the processing window contains edges or boundaries, these would be unduly smoothed because of a certain loss of edge information.

To avert the above mentioned drawbacks, a membership function based on the estimation of the noise level is implemented.

If the filter processing window coincides with a relatively homogeneous area of a picture, all the differences D_i will be close in terms of their absolute value and correlated to the noise. Thence, it is possible to select a membership function that is able to generate threshold parameters Th1 and Th2 that substantially coincide with D_{max}.

On the contrary, in case the pixel to be filtered belongs to an edge or boundary region of the image, the filtering action is made significant only where the differences among the pixels of the processing windows are small, that is to say, within the interval of the differences $|D_i|$ defined by $[D_{min};(D_{min}+D_{max})/2]$.

The threshold parameters Th1 and Th2 are then computed according to the following equations:

$$Th1 = K_n \cdot D_{max} + (1-K_n) \cdot D_{min} \tag{4}$$

$$Th2 = K_n \cdot D_{max} + (1-K_n) \cdot \frac{D_{max}+D_{min}}{2} \tag{5}$$

It is easy to demonstrate that Th1 is always greater or equal to Th2.

The range of the fuzzy variable "Low" may then be defined in terms of D_{max}, D_{min}, and K_n, where K_n influences the filter behavior according to the noise level determined for the area of the image defined by the processing window.

As far as K_n is concerned, in case the pixel to be processed belongs to a relatively homogeneous region of a picture affected by noise, D_{max} and D_{min} will be mainly correlated to the noise content and will have not so different values. In other words, this means that the difference $(D_{max}-D_{min})$ is relatively small.

If the pixel X to be processed belongs to an edge or boundary line, the difference $(D_{max}-D_{min})$ will be large. Hence, the value of K_n, is obtained, according to the method of the invention, by using a weighed function of the type depicted in Figure 2.

The parameter A depends on the brightness of the pixel to be processed. For example, it can be established on:

$$A = x/\lambda \tag{6a}$$

$$A = (255-x)/\lambda \tag{6b}$$

By way of an example, a satisfactory value for λ may be 4.

In choosing the parameter A for equation (6a), a standard scheme of sensorial response to contrast as the so-called Human Visual System (HVS) may be taken into consideration.

According to Weber's law, equal increments on the logarithm scale of pixel luminance value are perceived to be equally different among from one another therefore:

$$\Delta(\log) \propto \Delta C \tag{7}$$

wherein ΔC represents the contrast variation.

This means that:

$$\Delta x/x = \alpha \tag{8}$$

where α is a constant.

Hence, when an edge region is encountered, the condition $\Delta x > \alpha x$ is complied with.

While Weber's law is generally used to detect the minimum gray level to be quantized without introducing any false contour effect, according to the method of this invention, Weber's law is used instead to modulate the filtering action in function of the luminance characteristics of the pixel being processed. If the parameter A is chosen according to the relationship (6b), a stronger filtering action is implemented in dark areas than in bright areas of the image, if compared to that would be obtained by using equation (6a), this in consideration of the fact that the human eye is more sensible

to variations due to Gaussian noise in dark areas than in bright areas.

DESCRIPTION OF THE ARCHITECTURE OF THE INVENTION

A functional block diagram of a system implementing the above described technique is illustrated in Figure 4.

After "constructing" the required processing window, according to common buffering techniques, which obviously involve information relative to the pixels belonging to at least two successive scanning lines or rows, a dedicated DIFFERENCE COMPUTATION circuit computes the differences D_i (D1, D2,.....,D7) between the pixel luminance values (X1, X2, ..., X7) of the processing window neighbouring the pixel X being processed.

The block, D_{max} & D_{MIN} DETECTION, identifies and selects by making them available through two dedicated outputs, the maximum and minimum values of the differences D_i input to the block.

A first fuzzy logic *Adaptive Threshold Detection* processing block receives as input the pair of values D_{max} and D_{min} of the current set of differences D_i and computes the parameter K_n according to the following function referred to as MEMBERSHIP 1, shown in Figure 2 and expressed by:

$$\text{if } x > A \Rightarrow K_n = 0$$

$$\text{if } 0 \le x \le A \Rightarrow 1 - (x/A)$$

generating a corresponding pair of threshold values Th1 and Th2, according to equations (4) and (5), respectively.

A second fuzzy logic LOCAL ADAPTIVE NOISE SMOOTHING processing block carries out the independent processing of each of the differences D_i, using the previously generated threshold parameters Th1 and Th2 according to the function referred to as MEMBERSHIP 2, which may be depicted as done in Figure 3, and defined by:

$$\text{if } |D_i| < Th1 \Rightarrow K_i = 1$$

$$\text{if } |D_i| > Th2 \Rightarrow K_i = 0$$

$$\text{if } Th1 \le |D_i| \le Th2 \Rightarrow K_i = \frac{|D_i|}{Th1 - Th2} - \frac{Th2}{Th1 - Th2}$$

producing a set of output values K_i, each representing the measure of the degree of similarity between the pixel to be filtered, X, and a respective neighbouring pixel X_i and inside the processing window, according to equation (3).

A final filtering block separately processes each of the difference values D_i in function of the respective weighing coefficient K_i and, through a final adder stage Σ, produces the X_{out} pixel as the sum of the weighed contributions, according to equation (2).

The processing window can be easily realized by a circuit as that shown in Figure 5, whose functioning is immediately comprehended by a person skilled in the art.

It is evident that the memory requisite is substantially limited to the information of a simple scan line or row (Line Memory) and therefore it is a minimum fraction if compared to the memory requisite needed to store a whole field or picture.

A functional diagram of the block DIFFERENCE COMPUTATION and D_{MAX} & D_{MIN} DETECTION is illustrated in Figure (6).

Even in this case the circuit functioning is readily comprehended by a skilled person.

The ADAPTIVE THRESHOLD DETECTION block is schematically detailed in Figure 7.

According to a preferred embodiment, a fuzzy logic processing block according to a certain membership function (MEMBERSHIP 1), receives as input the difference values D_{min} and D_{max}, the value of the pixel under processing and a certain parameter λ and outputs a value K_n which, applied to the threshold generating blocks TH1 Gen and TH2 Gen, conditions the generated threshold values Th1 and Th2.

Structural details of the LOCAL ADAPTIVE NOISE SMOOTHING and FINAL FILTERING block are shown in the functional diagram of Figure 8.

The plurality of fuzzy logic circuits (MEMBERSHIP 2), generate a set of weighing coefficients K_i, by processing each difference value according to the threshold pairs Th1 and Th2 previously generated by the circuit of Figure 7. The membership function used may be the one depicted in Figure 3.

The computation of the set of coefficients K_i allows to curt the noise level through the FINAL FILTERING block by using a number of partial filters suitable to produce a corresponding set of weighed contributes $X(i)_{out}$ that are then added by the final adder Σ which outputs the correct pixel X_{out}.

Claims

1. A method of filtering Gaussian noise contained in a data stream relative to a certain field scanned by rows, characterized in that it comprises

   storing the information of a preceding scanned row defining together with the data of a row being currently scanned a certain bidimensional processing window of a certain number of pixels;

   computing the difference (D_i) between the value of a pixel (X) of the row being scanned and the value of the neighbouring pixels (X1, X2,...,X7) belonging to said processing window and determining the minimum (D_{min}) and the maximum (D_{max}) of the computed differences;

   processing by fuzzy logic the values of said pixel (X), of said minimum and maximum differences (D_{min}, D_{max}) and of at least a parameter (λ), derived from a certain sensorial response (HVS), according to a first membership function (MEMBERSHIP 1), generating a first weighing coefficient (K_n);

   generating a pair of threshold values (Th1, Th2) of said differences according to said first weighing coefficient (K_n);

   processing by fuzzy logic each of said computed differences (D_i) and said pair of threshold values (Th1, Th2), according to a second membership function (MEMBERSHIP 2), producing a corresponding set of weighing coefficients (K_i);

   combining each of said computed differences (D_i) with a respective weighing coefficient (K_i);

   adding the results of said combinations producing a corrected value (X_{out}) of said pixel (X).

2. The method according to claim 1, characterized in that said first weighing coefficient (K_n) is generated by using a membership function (MEMBERSHIP 1) defined by:

$$\text{if } x > A\ K_n = 0$$

$$\text{if } 0 < x < A \Rightarrow K_n = 1 - (x/A)$$

3. The method according to claim 1, characterized in that said pair of threshold values (Th1, Th2) is generated according to the following equations

$$Th1 = K_n * D_{max} + (1-K_n) * D_{min}$$

$$Th2 = K_n * D_{max} + (1-K_n) * \frac{D_{max} + D_{min}}{2}$$

4. The method according to claim 1, characterized in that said weighing coefficients (k_i) are generated using a membership function (MEMBERSHIP 2) defined by:

$$\text{if } |D_i| < Th1 \Rightarrow K_i = 1$$

$$\text{if } |D_i| > Th2 \Rightarrow K_i = 0$$

$$\text{if } Th1 \le |D_i| \le Th2 \Rightarrow K_i = \frac{|D_i|}{Th1 - Th2} - \frac{Th2}{Th1 - Th2}$$

5. A system of adaptive filtering to curb Gaussian noise within a same field of an image, characterized in that it comprises

buffering circuits of respective data sequences relative to a certain row of said field being scanned and to at least a previously scanned row of the same field, capable of defining a bidimensional processing window of pixels belonging to said consecutive rows (X, X1, X2, X3, X4, X5, X6, X7);

a circuit computing the differences (D_i) between the value of a certain pixel (X) and the neighbouring pixels (X1,...,X7) of said processing window and that determining the maximum and minimum computed difference (D_{max}, D_{min});

a first fuzzy logic processor (MEMBERSHIP 1) adaptively generating a pair of minimum and maximum threshold values (Th1, Th2) of said computed differences (D_i), depending on the value of said pixel (X), of said minimum and maximum difference (D_{min}, D_{max}) and of at least a parameter (λ) derived from a certain predefined sensorial response (HVS), according to a first membership function;

a plurality of second fury logic processors (MEMBERSHIP 2), each combining a respective difference (D_i) with said pair of threshold values (Th1, Th2), according to a second membership function and generating a respective weighing coefficient (k_i);

a plurality of combinating logic circuits (PARTIAL FILTER$_{(i)}$) each modifying a respective difference value (D_i) according to the respective weighing coefficient (k_i);

an adder circuit adding the modified values of said computed differences (D_i) and outputting a corrected pixel value (X_{out}) of said pixel (X).

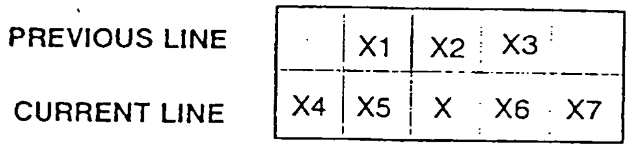

FIG. 1

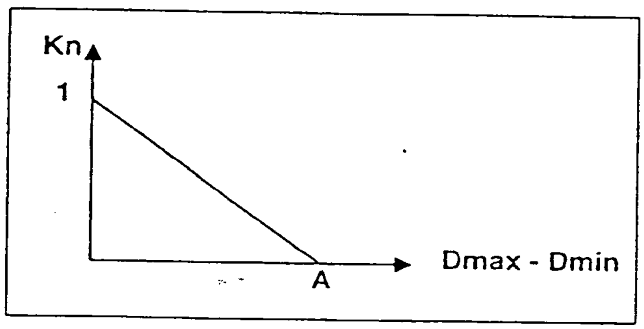

FIG. 2

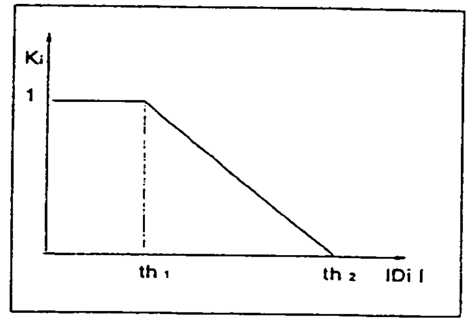

FIG. 3

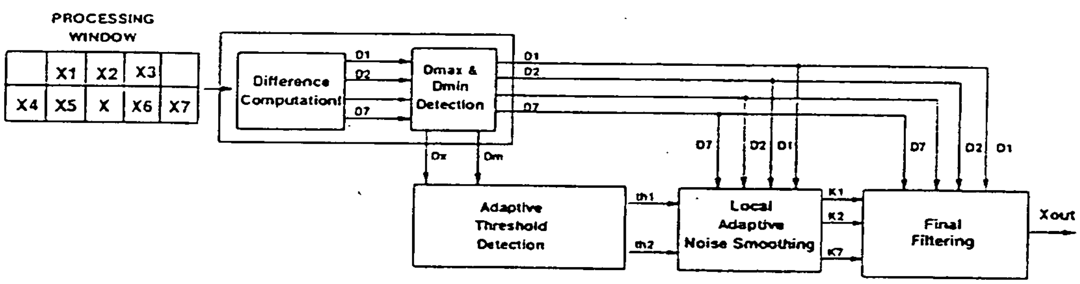

FIG. 4

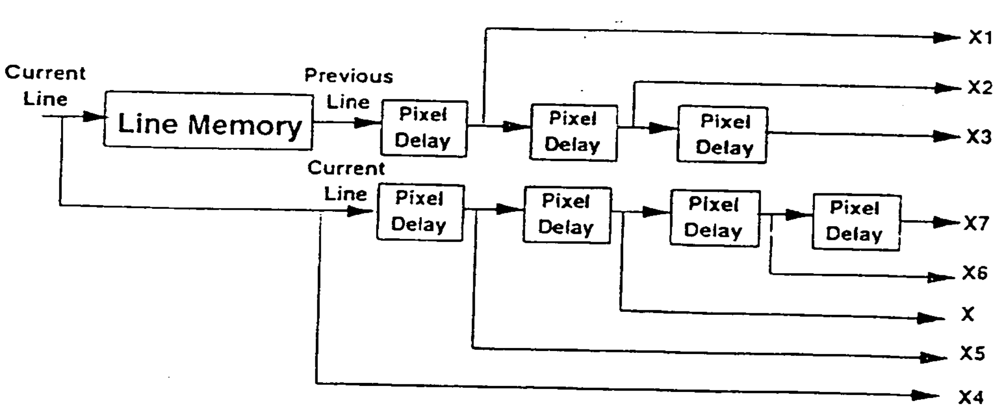

FIG. 5

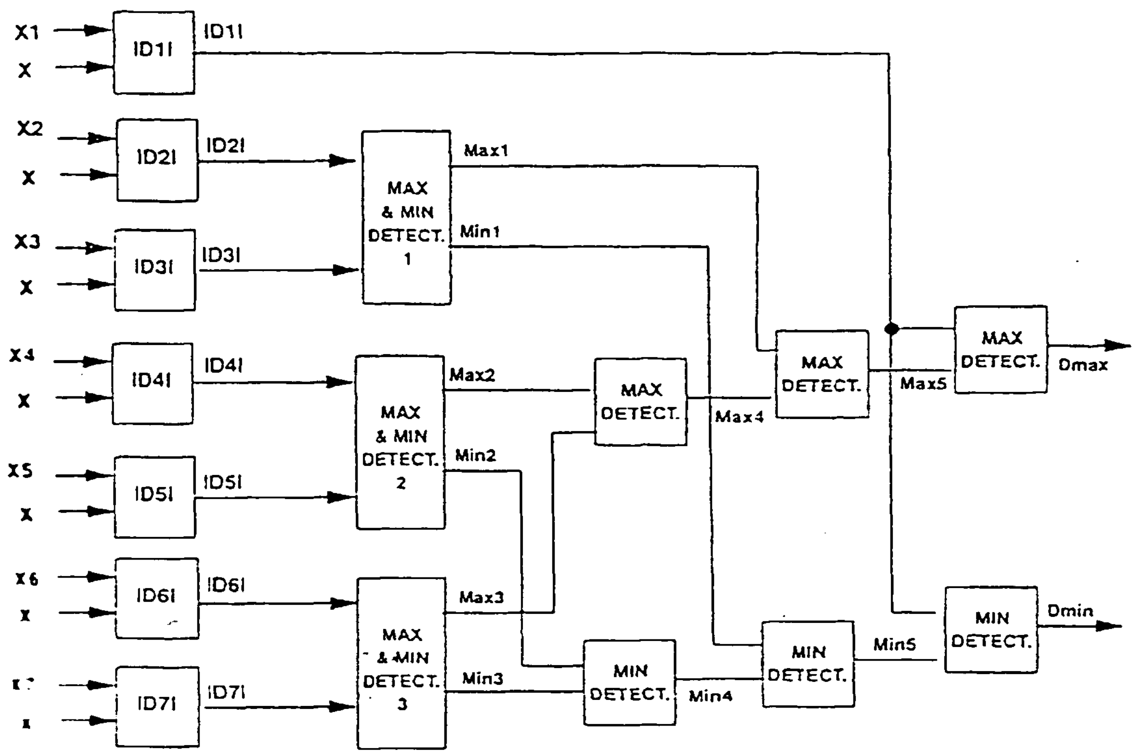
X1
X
ID1I
ID1I
X2
X
ID2I
ID2I
X3
X
ID3I
ID3I
X4
X
ID4I
ID4I
X5
X
ID5I
ID5I
X6
X
ID6I
ID6I
X
ID7I
ID7I
MAX & MIN DETECT. 1
MAX & MIN DETECT. 2
MAX & MIN DETECT. 3
Max1
Min1
Max2
Min2
Max3
Min3
MAX DETECT.
Max4
MAX DETECT.
Max5
MAX DETECT.
Dmax
MIN DETECT.
Min4
MIN DETECT.
Min5
MIN DETECT.
Dmin

FIG. 6

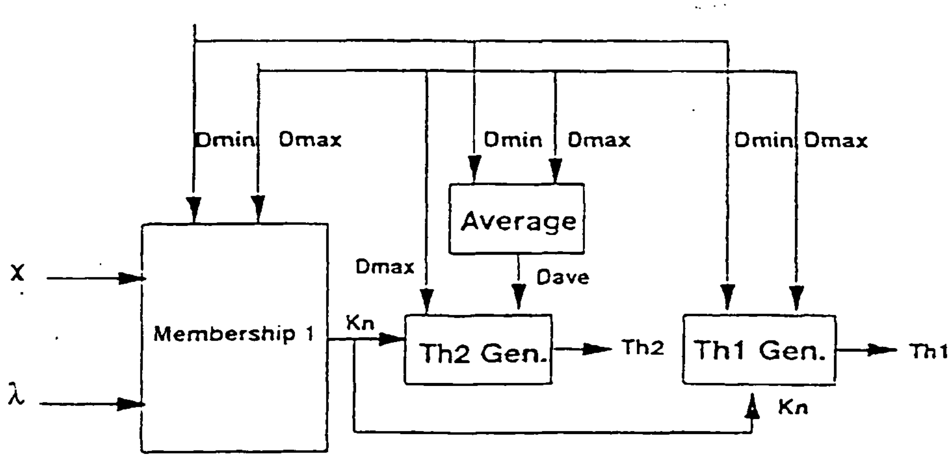
Dmin
Dmax
Dmin
Dmax
Dmin
Dmax
Average
Dave
Dmax
X
λ
Membership 1
Kn
Th2 Gen.
Th2
Th1 Gen.
Th1
Kn

FIG. 7

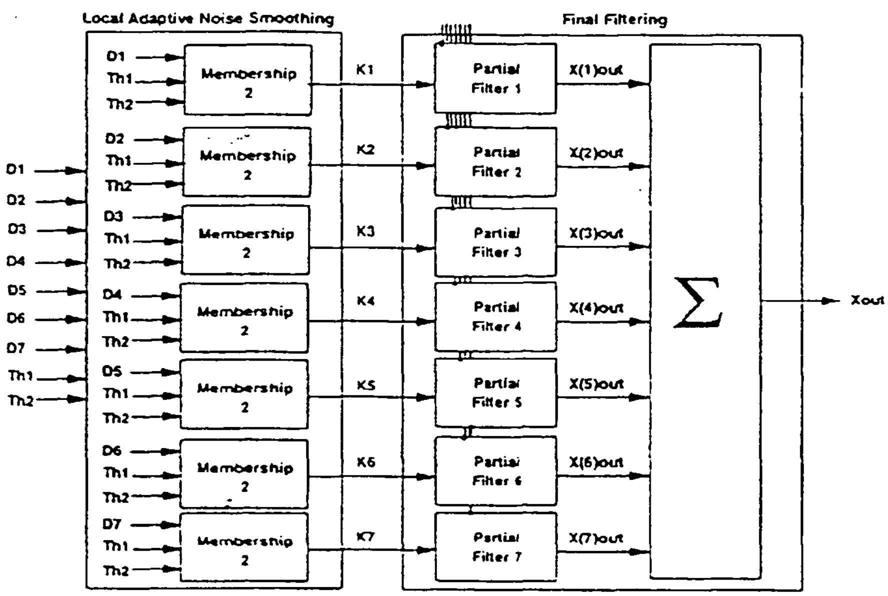
Local Adaptive Noise Smoothing
Final Filtering
D1
D2
D3
D4
D5
D6
D7
Th1
Th2
Membership 2
K1
K2
K3
K4
K5
K6
K7
Partial Filter 1
Partial Filter 2
Partial Filter 3
Partial Filter 4
Partial Filter 5
Partial Filter 6
Partial Filter 7
X(1)out
X(2)out
X(3)out
X(4)out
X(5)out
X(6)out
X(7)out
Σ
Xout

FIG. 8

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 83 0217

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 698 990 A (SGS THOMSON MICROELECTRONICS) * abstract * * column 2, line 52 - column 4, line 20 * ---	1-5	G06T1/00 G06T5/20
A	EP 0 415 648 A (CANON KK) * abstract * * column 5, line 31 - column 6, line 22; figures 1B,9B * ---	1-5	
A	SHEN Q: "FUZZY INTRAFRAME SMOOTHING OF A NOISY IMAGE" ELECTRONICS LETTERS, vol. 26, no. 13, 21 June 1990, pages 908-910, XP000107936 * the whole document * -----	1-5	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

G06T

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 November 1997	Gonzalez Ordonez, O

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

PREVIOUS LINE	·	X1	X2	X3	
CURRENT LINE	X4	X5	X	X6	X7

FIG. 1

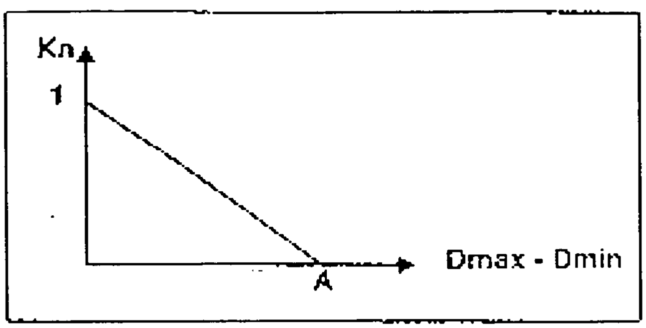

FIG. 2

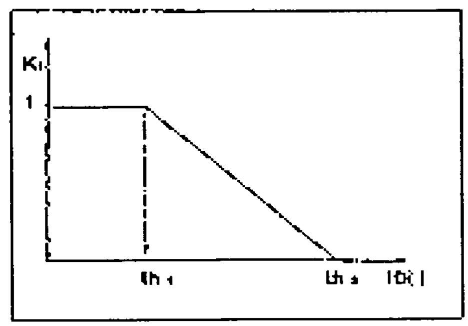

FIG. 3

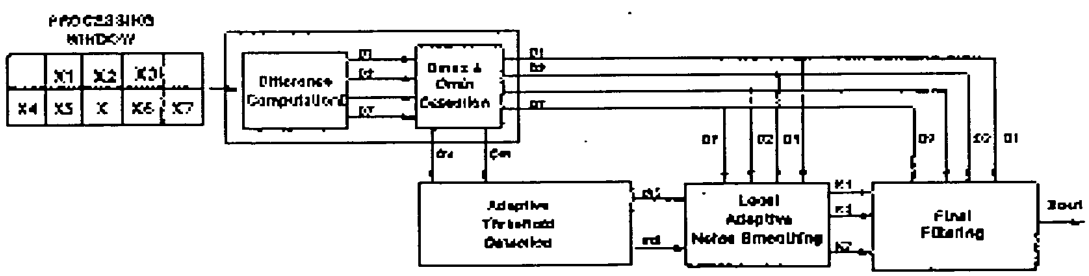

FIG. 4

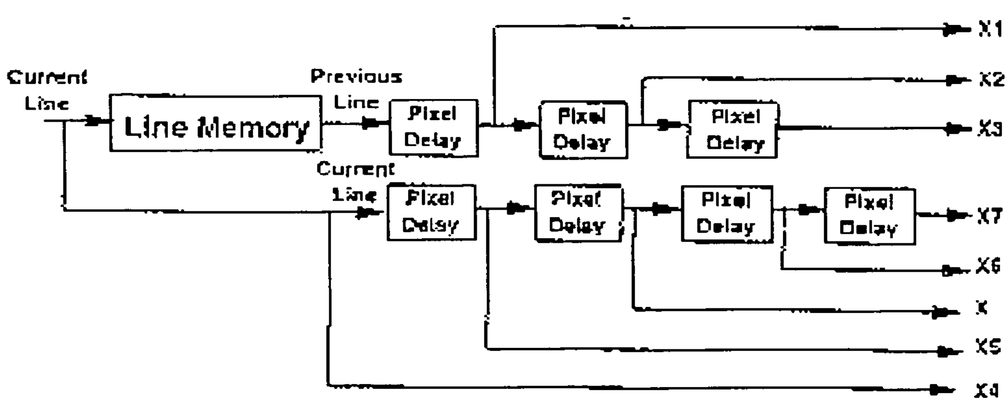

FIG. 5

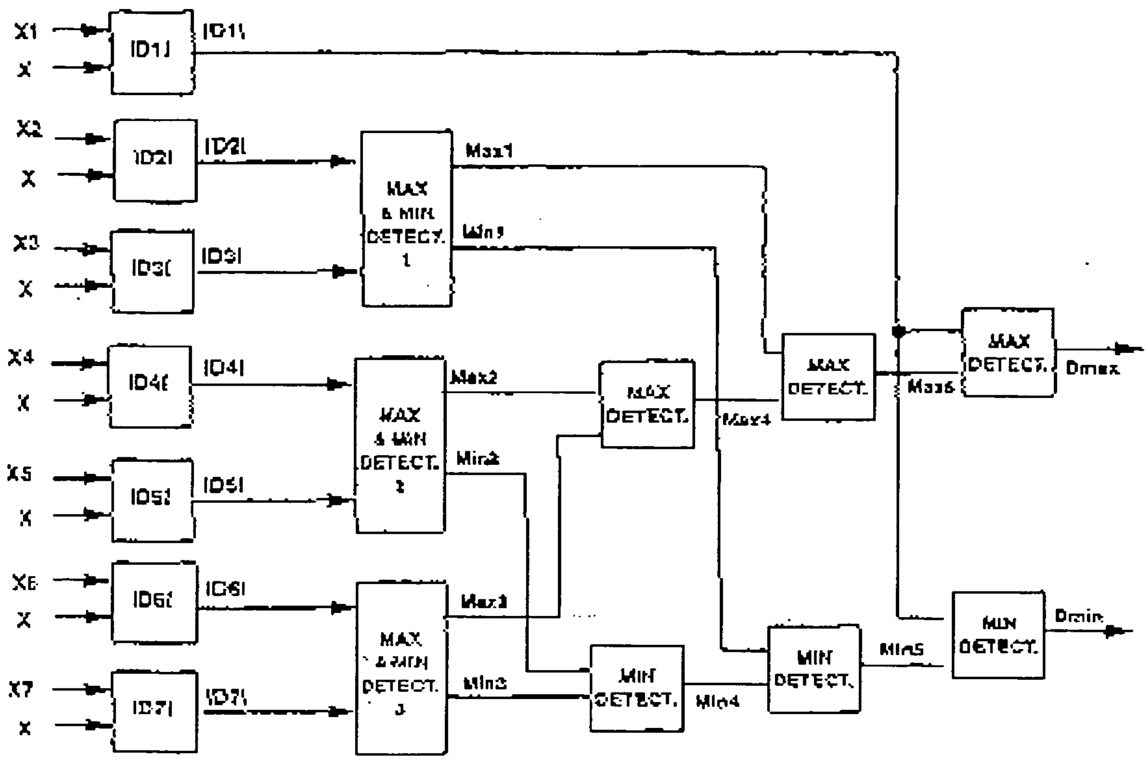
X1
X
ID1
ID1
X2
X
ID2
ID2
X3
X
ID3
ID3
X4
X
ID4
ID4
X5
X
ID5
ID5
X6
X
ID6
ID6
X7
X
ID7
ID7
MAX & MIN DETECT. 1
MAX & MIN DETECT. 2
MAX & MIN DETECT. 3
Max1
Min1
Max2
Min2
Max3
Min3
MAX DETECT.
MAX DETECT.
MAX DETECT.
MIN DETECT.
MIN DETECT.
MIN DETECT.
Max4
Max6
Min4
Min5
Dmax
Dmin

FIG. 6

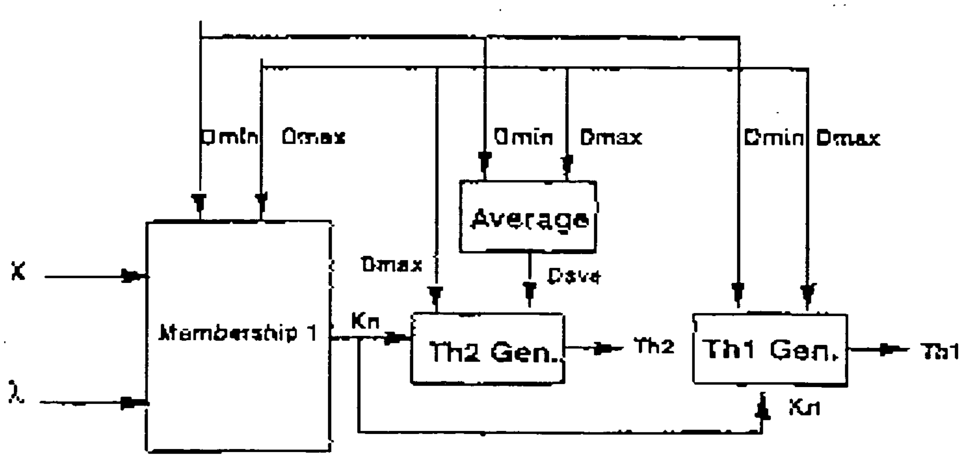
Dmin
Dmax
Dmin
Dmax
Dmin
Dmax
Average
Dmax
Dave
X
λ
Membership 1
Kn
Th2 Gen.
Th2
Th1 Gen.
Th1
Kn

FIG. 7

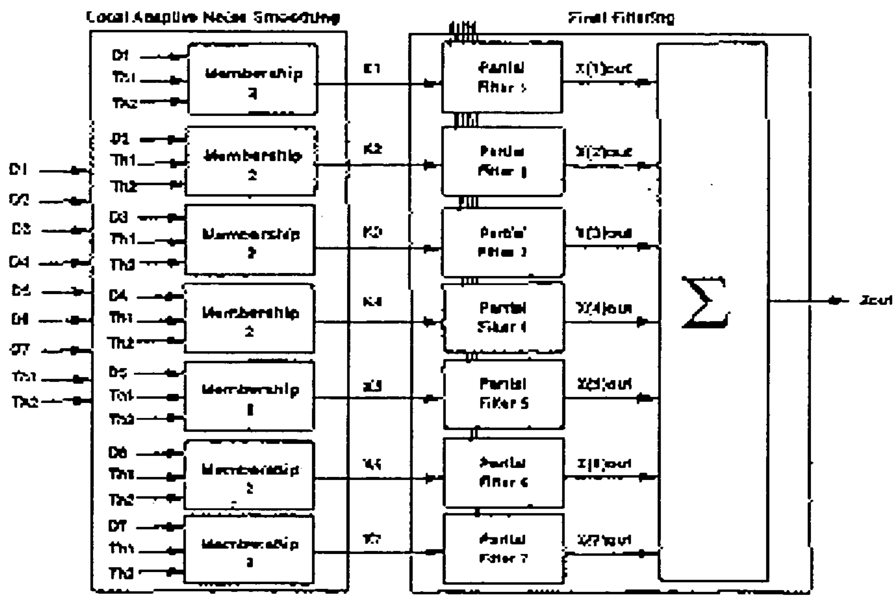
Local Adaptive Noise Smoothing
Final Filtering
Membership
Partial Filter 5
Σ
D1
D2
D3
D4
D5
D6
D7
Th1
Th2
K1
K2
K3
K4
K5
K6
K7
X(1)out
X(2)out
X(3)out
X(4)out
X(5)out
X(6)out
X(7)out
Xout

FIG. 8